Center for Independent Experts (CIE) Independent Peer Review of Sea Scallop Survey Methodologies and Their Integration for Stock Assessment and Fishery Management

17-19 March 2015

Waypoint Event Center at the Marriott Fairfield Inn and Suites, New Bedford, MA

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Executive Summary

The sea scallop dredge (NEFSC and VIMS) and optical surveys (SMAST and HABCAM V2 & V4) independently pursue a number of key objectives along with various secondary objectives. Each survey method has its own strengths and weaknesses and none are specifically designed to be supplementary or complementary to other.

There is a critical need for the development of an overall strategy to ensure that all survey methods are consistent with each other. All currently available information should be used to review each survey method and subsequently develop both supplementary and complementary surveys to improve the coverage and quality of the estimates derived from these surveys. The robustness of current and proposed survey methods and/or combined survey methods should be tested with the use of simulations.

What follows is a concise summary of the strengths and weaknesses of the reviewed sea scallop surveys, both individually and when used in combination.

Dredge surveys

Strengths

NEFSC dredge surveys conducted on research vessels have a long history and the time series of data should be maintained. VIMS dredge survey tows both a commercial and research dredge which provides data to determine the selectivity/efficiency of commercial gear. Calibrations indicate no differences between vessels towing the same dredge gear, after adjustment for tow distance.

Dredge surveys provide accurate measurements of shell height, accurate determination of live vs. dead scallops, no indication of dredge selectivity for 40+ mm scallops and sea state has been shown to have little or no effect on dredge scallop catches.

Most “prerecruits” (about 10-25 mm) pass through the dredge gear however very large numbers have been caught in some tows and provide a qualitative indication of a recruitment event. The physical capture of scallops in dredges is necessary to collect information for assessing fine scale ecology such as weight, growth and disease/parasite prevalence. Dredge surveys have been used for assessing Allee effects and predator-prey relationships.

Data from dredge surveys use standard design-based methods to estimate abundance and biomass. Data collected from VIMS+NEFSC dredge surveys are combined for analysis and estimation of sea scallop abundance and biomass.

Dredge surveys have generally recorded detailed information on fewer species than the optical surveys, however dredges are effective at capturing a suite of bottom associated species. The selectivity of the dredge gear differs from other commercial fishing gears and this may assist with a greater understanding of non-scallop species captured in those fisheries.

Weaknesses

Recent collected survey data could be used to better redefined strata and then post-stratify historical strata. Given the increases in sea scallop abundance the tow length should be reduced to increase the number of stations sampled. Simulation testing of the appropriate tow length should be carried out.

Reduction in area surveyed by the NEFSC dredge survey introduces some uncertainty in the quality of the survey abundance and biomass estimates. The systematic sampling design of the VIMS dredge survey is recognised as inefficient.

Dredges do not capture all available scallops (40% on sand and 24% on gravel). In addition it is possible dredges have a dome-shaped selection pattern which would lead to negative bias in the proportion of very large scallops in dredge length frequency distributions.

Dredge survey sub-sampling procedures need refining to estimate between basket variations in scallop counts.

There are issues with the estimation of abundance and biomass relating to 1) the systematic sampling design for the VIMS survey, 2) unaccounted measurement error, 3) efficiency corrections.

Optical surveys

Strengths

The SMAST drop camera system involves non-invasive technology involving 4 types (large, small, side and still) of cameras adaptable to management changes and providing abundance and biomass estimates quickly at the end of the survey.

The HAMCAM surveys take continuous photos at 6/sec along transects, with HABCAM V2 surveys consisting of short distances between transects, but for small parts of the total area while the HABCAM V4 surveys typically consist of wide distances between transects covering a wider total area.

The vast amounts of data collected by optical (especially HABCAM) surveys may provide further insights into sea scallop ecology and improved understanding of broader ecological and ecosystem issues.

Optical surveys have higher detectability of scallops < 20 mm than the dredge surveys although recruitment information is still only qualitative. Automation of imaging processing procedures will improve speed of image analysis.

Optical surveys offer opportunities for collection of environmental variables and visual cues providing information for assessing fine scale ecology such as Allee effect and predator-prey relationships.

The non-invasive optical surveys are well suited for repeated, high-intensity observations of disturbance from fishing gear and the effects of opening and closing areas to fishing.

Abundance and biomass estimated from SMAST data are based on simple calculations using a two-stage sampling design. HABCAM abundance and biomass use geostatistical model-based methods for estimating abundance and biomass which have been tested through simulations.

Optical surveys have the most obvious potential for attached or sessile species. Optical surveys are useful for collecting information on sediment characteristics and associated flora which can be used for characterization of habitats. This information can then be used to investigate habitat suitability analysis for projection of species distributions. Optical surveys are providing information on behaviour patterns of scallop and non-scallop species.

Weaknesses

The use of systematic designs for optical surveys are generally inefficient for estimating abundance and biomass and these estimates may suffer from less precision than those estimated using stratified random sampling designs.

Accurate length measurements are dependent on the position of the scallop which is not always flat on the surface and instead may be either angled or off the surface distorting the measurement. Optical surveys are likely to produce less reliable estimates of the proportion of dead scallops due to identification difficulties.

Optical surveys are calibrated to mitigate many confounding factors (i.e. optical distortion, attenuation, etc.), however loss of images will occur due to loss of visibility as a result of water turbidity, image clouded by silt clouds, and sea scallops obscured by animals in the water, epiphytes and substrate.

Physical sea state, current and tides may limit the ability to use the optical equipment and human annotation error will lead to inaccuracies in the data collected. SMAST drop camera suffers from an edge-effect error while HABCAM edge-effect is subject to skill of annotator.

There is a need to avoid complacency in automation procedures by ensuring ongoing calibrations and regular ground truthing of observations as an essential research component of surveys.

There is a need to further develop optical survey sub-sampling procedures of images. Optical equipment may distort length distributions. Pre-recruits are more difficult to identify due to their size and sometimes cryptic behavior.

Optical surveys have issues relating to 1) the systematic sampling design, 2) unaccounted measurement error, 3) uncertainty due to edge corrections.

Geostatistical model-based methods to date have not produced a "best" model and misuse of models will produce erroneous abundance and biomass estimates.

Combining surveys

Strengths

Dredge and optical surveys give complimentary information.

Inverse variance weighted means (IVM) give more importance to surveys with lower standard errors and have the lowest standard error of any weighted mean.

Cokriging methods combine survey observations by taking advantage of the covariance between two or more regionalized variables that are related, and are appropriate when the main attribute of interest is sparse.

To a large extent the VIMS dredge and NEFSC dredge surveys are "integrated" because they cooperate to address survey gaps.

Better collaboration between research institutions with assist with further integration of surveys.

Weaknesses

Inverse variance weighted means are not consistent across spatial scales. For that reason, simple means have been used in most years to combine estimates of abundance and biomass. Inverse variance weighting is reliable only if there are reliable estimates of variance which is uncertain for surveys with systematic survey designs.

Cokriging analysis to date has resulted in very little improvements to abundance and biomass estimates.

Combining the best features of the two optical methods to produce an overall improved optical survey method should be considered.

Background

The project description in the statement of work for this review states: On April 20, 2012, the New England Fishery Management Council voted to task its Science and Statistical Committee (SSC) "to 1) review the sea scallop HabCam survey technology and methods to determine if the HabCam is appropriate at this time for performing annual sea scallop surveys; 2) review how HabCam results will be integrated into sea scallop assessments for determining biomass and fishing mortality, and determine the impacts of reduced survey coverage from current dredge and SMAST video surveys." Further discussions broadened the scope of this task to examine all of the primary survey methods for assessing sea scallop abundance. Methods include scallop dredge surveys conducted on research vessels, scallop dredge surveys conducted on commercial vessels, the drop camera survey implemented by SMAST, and the HabCam system developed by WHOI and NEFSC. The objectives of this broadened scope are to assess the strong and weak points of each sampling approach, and identify the complementary facets of each survey methodology and opportunities for each method as part of the scallop survey sampling program going forward.

The charge to the Review Panel, in the statement of tasks, is that the panel will review field and analytical procedures used by each survey in estimating sea scallop abundance and biomass and collecting biological data that contribute to resource assessment and management of sea scallops and other species. Describe the strengths, weaknesses and the opportunities for improvement in the surveys, including their methods and estimators, as an overall program that serves as a basis for abundance and biomass estimates used in annual area-based scallop fishery management procedures and triennial benchmark stock assessments. Finally, describe opportunities for using each survey in monitoring and managing resources other than sea scallops.

The review panel was composed of four scientists appointed by the Center for Independent Experts: Noel Cadigan, Martin Cryer, Jon Helge Vølstad, Brent Wise. The review panel was chaired by J.-J. Maguire as a member of the New England Fisheries Management Council Scientific and Statistical Committee. The review panel was assisted by the NEFSC Stock Assessment Workshop (SAW) Chairman, James Weinberg, Paul Rago, Acting Chief of the NEFSC Resource Evaluation and Assessment Division and Deirdre Boelke from the New England Fisheries Management Council. Toni Chute and Larry Jacobson from the NEFSC acted as rapporteurs. A total of 49 people participated in the sea scallop survey methodologies review meeting.

Review Activities

The Panel to Review Sea Scallop Survey Methodologies and Their Integration for Stock Assessment and Fishery Management met at the Waypoint Event Center at the Marriott Fairfield Inn and Suites, New Bedford, MA 17-19 March 2015 to review material prepared by four scientific teams conducting surveys on Sea Scallops (Arnie's Fisheries, NEFSC, SMAST and VIMS).

Before the meeting, material to be reviewed was made available to the review panel via a server on the NEFSC website according to the schedule included in the Statement of Work. Copies of presentations and rapporteur notes made during the meeting were also made available to the review panel via the same server on the NEFSC website.

The meeting opened on the morning of Tuesday March 17, with welcoming remarks by Bill Karp, NEFSC Science and Research Director and Jon Mitchell, Mayor of New Bedford. Participants and audience members introduced themselves. The remainder of March 17 was devoted to presentations by each of the four scientific teams. Several of the presentations on day 1 used all their allotted time with little left for questions and discussions. However, on the following days, more time was allowed for questions and discussions. Presentations were made by Paul Rago, Dvora Hart, Dave Rudders, Kevin Stokesbury, Scott Gallager, Richard Taylor, Burton Shank, Jui-Han Chang and Deirdre Boelke.

The Panel was well supported and ably chaired. I was impressed by the willingness and ability of the survey teams to respond to panel questions and was particularly grateful for the constructive comments provided by other review meeting participants.

The review panel agreed on bullet points to be included in the report in the afternoon of Thursday, March 19. Meeting participants and scientific teams were allowed in the room, but microphones were turned off. The Chair compiled and edited the draft Summary Report, which was distributed to the Panel for final review before being submitted to the NEFSC. Each reviewer drafted and submitted an independent reviewer's report to the Center for Independent Experts.

The reports generated by reviewers addressed the following Terms of Reference.

(These Terms of Reference are to be carried out by the scientists involved with scallop survey methods and analyses. The Peer Review Panel will then address the strengths and weaknesses of the various survey approaches and survey methodologies, with a focus on these Terms of Reference.)

1. Review the statistical design and data collection procedures for each survey system
    a. Dredge surveys conducted on research vessels
    b. Dredge surveys conducted on commercial vessels
    c. SMAST video drop camera system
    d. HabCam camera and sensor sled
2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide etc.)
3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).
4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.
5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.
6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.
7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.
8. Identify future research and areas of collaboration among investigators and institutions.

Acknowledgements

I would like to thank Manoj Shivlani and Roberto Koeneke for their organization of the trip and handling of the administrative issues.

Summary of Findings

Term of Reference 1. Review the statistical design and data collection procedures for each survey system

This Term of Reference was addressed in detail with substantial information provided by the survey teams on the statistical design and data collection procedures (i.e. manuals), and quality control procedures, for each survey system. Obviously these are critical for ensuring a scientifically credible basis for estimating sea scallop abundance and biomass and it is essential that each survey system has an appropriate statistical design and data collection procedures. Furthermore given the spatial nature of the management arrangements for sea scallop with open/closed areas and adaptive rotational areas further underlines the need for a solid statistical sampling design for each survey system. If it can be demonstrated that the survey designs are "best practice" and provide accurate and precise abundance and biomass estimates then the increased confidence of stakeholders in the overall management arrangements should guarantee acceptance of ongoing management actions taken to ensure the sea scallop stock remains sustainable.

Dredge Surveys

Strengths

NEFSC dredge surveys conducted on research vessels have a long history commencing in 1960, although only since 1979 were they conducted annually using a stratified random statistical sampling design. Original stratification was based on historical shellfish strata however recent post-stratification were undertaken for strata that were split by a closed area boundary. These strata were divided into open and closed portions which resulted in reduced variance in stratified means, and allowed for comparisons to be made between open and closed areas. Since 2001, station allocations to strata have been adaptive, based on the standard deviations of tows within strata from the previous year and the strata areas. The allocations were informed by the Neyman optimal allocations, but final allocations also considered the need to keep some coverage of all areas and the needs of management. When decisions were made to drop strata, in most cases these were areas of low densities of scallops however a few questionable strata were dropped where a portion of the strata was productive. Tows are 15 minutes, historically to ensure that adequate numbers of scallops were sampled.

VIMS has conducted cooperative industry based dredge surveys utilizing commercial sea scallop vessels as the platform since 1999. The area surveyed is constrained by depth (offshore), NEFSC strata and prior survey information. The current survey design uses a systematic design (grid) with random start points and with subsequent surveys having unique starting points. The number of stations is determined by sample size analysis based on prior abundance data and availability of commercial vessel time. This survey tows two dredges – a commercial Coonamessett farm turtle deflector dredge and the NEFSC research survey dredge which provides the means to determine the selectivity/efficiency of the commercial gear. Similarly tows are 15 minutes historically to ensure that adequate numbers of scallops were sampled.

Weaknesses

In both dredge surveys, recent collected survey data could be used to better redefine strata and then post-stratify historical strata. This should lead to improved precision of abundance and biomass estimates. Given the increases in sea scallop abundance it should also be possible to reduce tow length to 7-10 mins to increase number of stations and hence overall spatial coverage. The availability of HABCAM data from tracts that cover the same areas as dredges could be used in simulations to determine appropriate/optimal tow length and I would encourage this analysis as a priority.

The recent reductions in sample sizes and coverage for the NEFSC dredge survey introduces some uncertainty in the quality of the survey abundance and biomass estimates (possibly less precision and potential bias). The stratification and quasi-optimal allocation for this dredge survey appeared suitable, but insufficient detail about the specific sampling plans or any analysis of its potential efficiency compared to stratified simple random sampling were available to make a more definitive conclusion. Should the reductions in sample sizes and coverage be ongoing or further reductions occur it would be essential to investigate the impact of these on the quality of survey abundance and biomass estimates.

The systematic sampling design of the VIMS dredge survey has been recognised as inefficient for estimating abundance and biomass and causing difficulty in producing an unbiased estimator of the variance of the abundance and biomass estimate, due to the same sampling intensity in areas of low and high scallop abundance instead of obtaining more precise estimates by greater sampling in areas of high abundance. There is a proposal to change to stratified random design using modified shellfish strata and an adaptive allocation approach for selecting stations. However I would urge the researchers to consider the impact of this change in design on future integration with the NEFSC dredge survey data. While the integration of the NEFSC and VIMS surveys is examined under a later Term of Reference (7), it would appear to be an obvious approach for increasing overall spatial coverage of the dredge surveys although it would be important to maintain the continuity of the dredge time series of abundance and biomass estimates.

Optical Surveys

Strengths

SMAST drop camera system is based on centric systematic design with four camera drops per station with live video feed from 4 types (large, small, side and still) of cameras sent to wheelhouse where it is recorded and analysed on-board. The SMAST drop camera system developed in 1999 originally focused in on estimating biomass in closed areas, but coverage expanded progressively and provided annual abundance and biomass estimates from 2003 (except for 2013 due to lack of resourcing). This is a cooperative survey with the fishing industry using commercial vessels, involving non-invasive technologically simple gear, adaptable to management changes and providing abundance and biomass estimates quickly at the end of the survey. Overall the SMAST drop camera surveys provide good sampling intensity of areas surveyed.

HABCAM V2 has been in operation since 2005, primarily deployed from the F/V Kathy Marie (Arnie's Fisheries) involving a single camera with 4 strobes, altimeter, CTD, towed from a fiber-optic winch. This system is used to undertake fine scale surveys. HABCAM V4 has been in operation since 2012, mainly deployed from the R/V Sharp, but also on a recent cruise on the R/V Connecticut. The system involves stereo cameras, with additional oceanographic sensors and side-scan sonar. This system is used to undertake broadscale surveys. Both systems are towed at 5-7 knots, taking continuous photos at 6/sec. The HAMCAM V2 survey generally follows a systematic transect sampling design with high intensity sampling along transects. Work is continuing on finalizing a statistical sampling design for surveys using the HABCAM V4.

The HABCAM surveys provide very detailed information along transects with the HABCAM V2 surveys consisting of short distances between transects, but for small parts of the total area while the HABCAM V4 surveys typically consisting of wide distances between transects covering a wider total area.

Weaknesses

As explained above the use of systematic surveys are generally inefficient for estimating abundance and biomass and these estimates are less precise than those estimated using stratified random sampling designs.

While a key strength of these surveys is the vast amounts of data collected which may provide insights into broader ecological and ecosystem issues, there is a tendency by the researchers to pursue multiple objectives as a result of all the additional data. These considerations along with the current spatial management measures may justify the continued use of systematic sampling designs, however an optimal survey design should depend on the primary purpose of the survey and compromises are necessary if multiple objectives are to be addressed.

I would encourage further research utilising the data collected to date for the development of optimal statistical sampling designs for these optical survey methods. Understandably this will not be a simple task as these surveys introduce new sampling problems that will need to be solved (refer to the sections for Terms of Reference 2 and 3).

Conclusions and recommendations for Term of Reference 1

The use of both dredge and optical surveys should be considered a necessity for the estimation of sea scallop abundance and biomass. It is therefore essential that each survey system has appropriate data collection procedures and statistical design. While a number of weaknesses were identified these are all resolvable with adequate resourcing. However as these survey methods improve and change over time new weaknesses may emerge that will require investigation and rectification, thus ongoing review of survey methods should be considered an essential research component. There were proposals presented during the review meeting which would change various aspects of some survey designs and other survey methods which are still currently undergoing further development. I would urge the researchers to consider the impact of any changes in survey design on future possible integration of surveys and the impact on maintaining the continuity of the time series of abundance and biomass estimates. Finally I would like to encourage the development of an overall sampling strategy to ensure that all survey methods are statistically consistent with each other.

Term of Reference 2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (e.g., light, turbidity, sea state, tide etc.)

This Term of Reference was addressed satisfactory with substantial information provided by the survey teams on the key factors contributing to measurement error of observations. As with the previous Term of Reference understanding and eliminating measurement error of observations is critical to producing accurate and precise estimates of sea scallop abundance and biomass. It was apparent from the presentations and background information that dredge surveys are necessary for the collection of samples that required physical and laboratory examination of specimens, while optical surveys provide additional information not sampled adequately by the dredge surveys. However dredges have also been used to validate data produced by the optical surveys. Consequently evaluations of measure error observations were made on the basis of comparisons between dredge and optical surveys.

Dredge Surveys

Shell height measurement strengths and weaknesses

Scallop shell heights were measured on mechanical measuring boards prior to 2005, and electronic boards thereafter. The mechanical boards binned the measurements into 5 mm size groups, whereas the electronic boards measure scallops to the nearest millimeter. Investigation of measurement errors concluded that the shell height measurement error using either the mechanical or the electronic boards is about 2 mm. It can be concluded dredge surveys with electronic boards provide accurate measurements of shell height.

Detection of scallops strengths and weaknesses

Comparisons with optical surveys have demonstrated that dredges do not capture all available scallops. The optical surveys have been used to estimate the efficiency of dredge surveys: 40% on sand and 24% on gravel, i.e. the dredge catches 40% of what the optical systems saw on sand and 24% of what the optical systems saw on gravel.

Determination of live vs. dead scallops strengths and weaknesses

Determination of live vs. dead scallops is included in the sampling protocols and is a straightforward determination. Any “clappers” (dead scallops with the two valves still attached at the hinge) are measured and recorded with their own “species” code to distinguish them from the live scallops used in the abundance indices. Dredges can be provide accurate determination of live vs. dead scallops.

Selectivity of gear strengths and weaknesses

Calibrations indicate no differences between vessels towing the same gear, after adjustment for tow distance: R/V Albatross IV 1963-1989, 1993-2007 vs R/V Hugh Sharp 2008 present (HABCAM V4) vs Nordic Pride (VIMS) vs Kathy Marie (HABCAM V2). Tow distance is reasonably simple to measure as a function of depth and nominal tow distance. In addition VIMS dual gear systems allows for calibration of commercial gear against research gear and they provide the ability to estimate exploitable abundance and biomass.

Comparison of dredge and optical size-frequencies and accounting for measurement errors gives no indication of dredge selectivity for 40+ mm scallops. However, there is some potential for dredges to have a dome-shaped selection pattern which would lead to negative bias in the proportion of very large scallops in dredge length frequency distributions.

Influence of confounding factors strengths and weaknesses

Most tows were conducted when wave heights were less than 1 m, but there were some tows conducted with waves as high as 5 m. Generalized Additive Models (GAMs) were used to evaluate possible effects of sea state on dredge catches. While wave height was significant in some models it had only a marginal effect on the explained deviance and it was concluded that sea state has little or no effect on scallop catches.

Optical Surveys

Shell height measurement strengths and weaknesses

While the optical survey instruments are calibrated to ensure accurate length measurements the position of the scallop is not always flat on the surface but instead either angled or off the surface, distorting the measurement. Errors have been shown to exceed 30% due to angular displacement and up 100% due to distance from the camera for swimming scallops. One study estimated HABCAM measurement error as 13 mm compared to 11 mm for the SMAST survey when comparing to length frequencies collected by dredge surveys.

Improvements to length measurement were discussed during the review meeting and including using the correlation between the shell heights (umbo to ventral margin) and shell width (lateral margins) and the use of stereo cameras.

Detection of scallops strengths and weaknesses

Optical surveys have higher detectability of scallops < 20 mm than the dredge surveys. Optical surveys provide almost complete detection of exploitable (40+ mm) sea scallops and better detection of recruitment (10-25 mm) compared to dredge surveys; however recruitment information is still only qualitative.

Small sea scallops are difficult to distinguish from the substrate or epifauna and their detection is more likely to be subjected to the influence of confounding factors (see below).

Determination of live vs. dead scallops strengths and weaknesses

Detailed protocols have been developed for determining live vs. dead scallops from images. Not all qualities presented in the guides are visible for every sea scallop however any of the qualities indicate a live scallop. The ability to view the sea scallop in 3D (SMAST side camera and HABCAM stereo cameras) aids greatly with the identification of clappers.

Overall optical surveys are likely to produce less reliable estimates of the proportion of dead scallops (false alive or dead) than dredge surveys and the magnitude of detection should be quantified.

Selectivity of gear strengths and weaknesses

The SMAST large camera, small camera and digital still camera provide detection limits of small scallops in the range of 30-40 mm, 20-30 mm and as small as 10 mm respectively. HABCAM provide detection limits as small as 10-15mm.

Camera edge-effects are treated differently between HABCAM and SMAST Drop Camera surveys.

HABCAM surveys count all sea scallops that are more than half way in the image and use a border rule if the sea scallop is exactly half way in the image and in these circumstances only count sea scallops that are half way in the top and right sides. The issue here is the ability for the annotator to determine if the sea scallop is exactly half way.

The SMAST drop camera edge-effect correction method inflates the sampled area by including a buffer around the actual quadrat of width equal to half the average length of the observed scallops. This approach will underestimate the abundance and biomass of small scallops because small scallops on the outer part of the buffer zone will not be visible in the quadrat and thus the effective sampled area will be overestimated. Conversely, very large scallops that are partly visible in the quadrat may extend beyond the buffer zone and thus the effective sampled area will be underestimated.

Inappropriate adjustments for camera edge-effects will lead to errors in estimates of the abundance and biomass of sea scallops. This bias is particularly important for exploitable biomass estimation because meat weight scales with a power of 3 or more on length. One solution offered by one of the panel review members was the use of the sea scallop shell hinge (or specific small location on the hinge) to determine if it should be included in the count.

Influence of confounding factors strengths and weaknesses

There are many confounding factors (i.e. optical distortion, attenuation, etc.) for optical surveys and many of these have been addressed in the SMAST drop camera and the HABCAM surveys. Rigorous camera calibration is a fundamental procedure that must be done to minimize measurement error. There are various calibrations undertaken and these are completed at regular intervals before and during the survey period.

Many issues lead to loss of images including loss of visibility due to water turbidity, image clouded by silt clouds, and sea scallops obscured by animals in the water, epiphytes and substrate. The physical sea state, current and tides may limit the ability to use the optical equipment. The impact of these are likely to vary depending on environmental, physical and substrate conditions (e.g. currents, slope, roughness of the bottom, other bottom types, etc.).

Perhaps one of the greatest confounding factors is human annotation error. HABCAM automation of imaging processing procedures are advanced and ongoing research in this area should help to overcome many of the human annotation errors. I would encourage ongoing improvements to the training of human annotators and further research in advancing automation of imaging processing.

Conclusions and recommendations for Term of Reference 2

The ability to use dredge and optical surveys to cross validate and where possible estimate biases and corrections for measurement error of observations is extremely valuable. This once again indicates the utility of both dredge and optical surveys as providing estimation and correction for measurement error of observations which will lead to more accurate and precise estimates of sea scallop abundance and biomass. While there has been considerable amounts of research in this area there are still a number of weaknesses identified that should be investigated. As video technology continues to improve there will be an ongoing need to re-evaluate the measurement error of observations. However this is not all bad as improvements in optical survey may provide further insights into the dredge surveys. There were many proposals presented during the review meeting for greater automation and while these should provide more accurate and precise measurements I would urge the need to avoid complacency and ensure ongoing calibrations and regular ground truthing of these automation features should be built in as an essential research component of surveys.

Term of Reference 3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (e.g., Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

This Term of Reference was addressed satisfactory with substantial information provided by the survey teams on the biological sampling aspects of the surveys. However it was noted that many of these are works in progress and require more research before the full utility of the data can be realised.

Dredge Surveys

Sub-sampling procedures strengths and weaknesses

In most tows, all scallops are measured. However, when catches are very large, only a subsample of the scallops are measured, and these measurements are expanded to the entire catch. In most such cases, the scallops are placed into baskets, the baskets are counted, and a random sample of 20% of the baskets are measured. The baskets in which scallops are placed are not recorded individually.

Sub-sampling procedures need refining and it is recommended that the total number of baskets and fraction sampled be recorded on dredge surveys, and that the between basket variation in scallop counts (for subsamples) be recorded. This could provide useful information on this source of variation.

Ability to sample all size classes strengths and weaknesses

Scallops that are 2 years old (typically 35-75mm Shell Height) are fully recruited to the lined research dredge (38mm liner). Scallops less than 2 years old are commonly observed but it is difficult to accurately delineate the spatial scale and magnitude of scallops at this size. There is some potential for dredges to have a dome-shaped selection pattern which would lead to negative bias in the proportion of very large scallops in dredge length frequency distributions.

Detection of incoming recruitment strengths and weaknesses

One year old “prerecruits” are about 10-25 mm when the surveys are conducted, so that most of these pass through the 38 mm liner and are not caught. However, very large numbers of one year old scallops have been caught upon occasion, and these observations are thought to be good predictors of a strong year class. Their presence is considered a qualitative indication of a recruitment event and represents an area to monitor.

Potential ability to assess fine scale ecology strengths and weaknesses

The physical capture of scallops using a dredge is necessary to collect other biological information such whole weights and shells for shell ring growth analysis. Collection of meats and gonads allows information such as disease prevalence (e.g. grey meat, blister disease) which provides important information about potential future natural mortality.

Atlantic sea scallops are dioecious broadcast spawners, and males and females must be in close proximity during spawning in order for substantial fertilization success. Dredge survey data have been used to show that scallop aggregations were much denser after closures, and hence fertilization success likely increased substantially. The increases in fertilized egg production were therefore likely much greater (Allee effect) than the (very substantial) increases in biomass in these areas.

Sea scallop predators, in particular sea stars (*Astropecten americanus, Asterias* spp.) and crabs (Cancer spp.) have been sampled and analysis of these data indicates that both the *A. americanus* sea stars and crabs are negatively related to sea scallop recruitment.

The physical capture of scallops provides useful data on biological parameters and assessing fine scale ecology such as weight, growth, disease prevalence, Allee effect and predator-prey relationships. Subsampling for these data should follow a statistical sampling design.

Optical Surveys

Sub-sampling procedures strengths and weaknesses

Screening occurs for poor images which are removed from subsequent analysis. All remaining images are available for subsampling. The SMAST drop camera survey produces 4 images per station, while the HABCAM surveys produces an image every 6/sec along the survey track. As such there are significant autocorrelations along the survey track. Analysis indicate that the sea scallop mean and CV remained stable up to a level of every 100th image, and therefore this would suggest the required subsampling rate is every 100th image. However the subsampling rate will depend on the objectives and species, where for example too great a spacing may miss small patches and widely spaced individuals.

Sub-sampling procedures should follow a statistical sampling design.

Ability to sample all size classes strengths and weaknesses

While the optical surveys have higher detectability of scallops < 20 mm than the dredge surveys, they provide less accurate information on the exploitable (i.e. 40 mm+) size composition because the optical sampling and analytical procedures introduce statistical noise. This leads to distributions of size (shell heights) being widened (very small and very large scallops can be "invented" by the optical systems) and cohorts being "smeared" together (an example was shown where a trimodal length frequency distribution appeared unimodal using an optical system).

Detection of incoming recruitment strengths and weaknesses

Optical surveys provide better detection of recruitment compared to dredge surveys; however recruitment information is still only qualitative. Pre-recruits are more difficult to identify due to their size and sometimes cryptic behavior. They are difficult to distinguish from the substrate or epifauna and their detection is more likely to be subjected to the influence of confounding factors.

Potential ability to assess fine scale ecology strengths and weaknesses

Optical surveys offer great opportunity for collection of environmental variables, visual cues (such as the presence of specific growths/epifauna) and rugosity (measured with side cameras) that may be correlated with sea scallop abundance and biomass.

Fine scale distribution and crowding levels of juvenile and adult sea scallops can be assess thus allowing assessment of an Allee effect. In addition because HABCAM images overlap, one-dimensional nearest neighbor distances can be calculated, and two-dimensional nearest-neighbor distances can be inferred thus allowing estimation of fertilization success based on field data.

Both towed and dropped cameras provide potential information on predator-prey interactions. Finfish avoidance is potentially more of a problem for the towed camera than for the drop camera because it is likely to be detected earlier by finfish than the drop camera would. However, the towed camera, given sufficient transects, provides more images that could be used to evaluate predator-prey distributions at a variety of spatial scales.

The non-invasive optical surveys are well suited for repeated, high-intensity observations of disturbance from fishing gear and the effects of opening and closing areas to fishing.

Overall the large numbers of images collected provides useful data for fine scale ecology such as Allee effects, predator-prey relationships and impact of fishing gear and the effects of opening and closing areas to fishing. Ongoing research into fine scale ecology is encouraged.

Conclusions and recommendations for Term of Reference 3

As was noted in the introductory paragraph to this Term of Reference section many of the biological sampling aspects of the surveys are works in progress and I would encourage these types of research studies to continue. the complexity and magnitude of work involved in processing large amount of image data collected is acknowledged, however determination of appropriate subsampling is an issue in both dredge and optical surveys and should follow a statistical sampling design. No single survey could sample all size classes nor provide a quantitative measure of recruitment. Whether combining data from different surveys is a realistic challenge, overcoming this limitation would lead to more accurate and precise estimates of sea scallop abundance and biomass. Greater understanding fine scale ecology provides important information about potential future growth, reproduction and natural mortality, which can greatly affect the efficacy of management plans and potential yield.

Term of Reference 4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

All presentations addressed this Term of Reference satisfactorily. Estimates of sea scallop abundance and biomass come from three sources – dredge surveys, SMAST drop camera survey and HABCAM surveys and these are reviewed and evaluated separately. An example provided at the workshop was the 2012 survey results presented as Table 1b. This table provides a summary of estimates of abundance and biomass from the three survey types for Mid Atlantic and George Bank sub-areas, regional and total area.

	Table 1b - Summary of 2012 Survey Results									
	Dredge		SMAST Video		Habcam		Mean	SE	IVM	SE
MidAtlantic	Bms(mt)	SE	Bms(mt)	SE	Bms(mt)	SE				
Delmarva	2299	220	4762	674	3005	798	3355	356	2566	202
HCSAA	6791	530	6532	1082	7139	642	6821	455	6882	382
ET	4570	803	7021	1419	8130	847	6574	612	6366	539
VB	102	55	NS	NS	NS	NS	102	55	102	55
NYB	11803	2084	4673	810	8750	1015	8408	819	6728	606
LI	13196	1273	13053	1147	10351	185	12200	575	10476	181
Stratum21	2077	265	2632	709	1540	426	2083	290	1992	214
Block Island	NS	NS	1803	463	821	NA	1803	463	1803	463
MidAtl	**40837**	**2648**	**40476**	**2516**	**39736**	**1736**	**41346**	**1418**	**36915**	**1068**
Regional-scale IVM									**40169**	**1257**
Georges Bank										
CL1ACC	4431	716	5789	1180	3054	356	4425	475	3494	307
CL1NA	1768	729	6990	3572	10230	877	6330	1250	5266	554
CL-2(N)	11207	1233	14921	4036	8183	2240	11437	1593	10799	1044
CL-2(S)	7007	1110	6014	1000	7404	707	6808	551	6955	512
NLS-Access	8598	699	4401	722	4434	324	5811	352	5062	273
NLS-NA	23	13	2412	857	NS	NS	2412	857	2412	857
SCC	12420	1353	10873	2610	10230	877	11174	1023	10878	708
SCH	6924	1011	11370	3649	14195	1201	10830	1324	10002	757
NEP	4004	1163	3933	983	5836	481	4591	532	5291	405
SEP	1027	124	2226	390	7111	NA	2226	390	2226	390
Georges Bank	**57408**	**2916**	**68930**	**7345**	**70677**	**2994**	**65672**	**2953**	**62385**	**1988**
Regional-scale IVM									**64248**	**2009**
Total	**98246**	**3939**	**109406**	**7764**	**110413**	**3460**	**106021**	**3276**	**99299**	**2257**
Overall IVM									**104417**	**2370**

Dredge surveys

Strengths

The VIMS and NEFSC dredge surveys are post-stratified into sub-areas and the standard design-based methods are used to estimate abundance and biomass within these sub-areas and then aggregated to regional and total abundance and biomass estimates.

The NEFSC survey uses a research dredge on the vessels, while the VIMS survey uses both a commercial and a research dredge. As explained in Term of Reference 2 section above, calibrations have demonstrated that there are no differences between vessels towing the same gear after adjustment for tow distance. On-board equipment including internal clock synchronized to GPS, time tilt sensor which measures angle of inclination, sensor measuring depth and video verification are used to provide accurate measures of tow distance.

The efficiency of both gears has been previously estimated and corrections applied to estimate abundance and biomass. The current estimates of dredge efficiency were derived from comparative work between HABCAM and the NEFSC dredge survey across a variety of habitats (40% on sand and 24% on gravel) and comparison of VIMS commercial and NEFSC survey dredge gear.

The estimate of abundance (or biomass) is essentially a mean abundance (or biomass) per survey tow (mean abundance or biomass/mean area swept per tow) scaled by both gear efficiency and the areal extent of the sub-area and then aggregated to regional and total abundance and biomass estimates as presented in Table 1b.

Weaknesses

The VIMS scientist identified that the abundance and biomass estimation has issues related to 1) the systematic sampling design for the VIMS survey, 2) unaccounted measurement error, 3) efficiency corrections. The VIMS scientist indicated the survey design will change to attempt to address some of these issues. However as discussed in the first Term of Reference section the impact of this change in design on future integration with the NEFSC dredge survey data should be considered.

The efficiency analysis assumes all scallops are observed in each HABCAM image which, as discussed in the Terms of Reference sections above, may not always be the case and any biases in the efficiency estimates (over time or space) will affect the accuracy of the survey abundance and biomass estimated.

SMAST drop camera surveys

Strengths

The survey design is a centric systematic design, and as such the calculations area are simple to obtain estimates of abundance and biomass. As mean shell height (and meat weight) of measured scallops differs with latitude and/or depth abundance and biomass are estimated separately for sub-areas similar to those used in the dredge survey estimations and then aggregated to regional and total abundance and biomass estimates as presented in Table 1b.

Mean densities and standard errors of scallops are calculated using equations for a two-stage sampling design. Where the mean of the 4 quadrats at station is averaged over all stations within the area. The abundance of scallops in the area is calculated by multiplying scallop density by the total area. Biomass is calculated using meat weight equations for Mid-Atlantic which includes a shell height/depth interaction term, and another equation for Georges Bank which includes a latitude term.

Weaknesses

While the estimation methodology, and variance estimators, for the SMAST drop camera survey appear appropriate, this survey used a survey design similar to the VIMS dredge survey, and hence the variance estimation for this survey also may have bias issues related to 1) the systematic sampling design, 2) unaccounted measurement error, 3) uncertainty due to edge corrections. The uniform allocation of stations is reasonable for multiple objectives but is likely to be inefficient for the estimation of abundance of exploitable biomass since substantial sampling effort is allocated to areas with minimal or zero abundance of scallops above 40 mm. As discussed in Term of Reference 2 and 3 above the bias associated with the method of correcting for edge effects and the detectability should be further investigated.

HABCAM surveys

Strengths

The HABCAM surveys produce a myriad of data and the issue becomes how to analyse the large numbers of samples which were highly zero inflated and where residuals are likely to be spatially autocorrelated due to patchiness of scallop distributions and sequential sampling. Two solutions investigated by the researchers were (i) aggregate data points (within segments along a survey track) into a single data point (ii) model data points (within segments along a survey track) as random effects. An additional research question was determining the appropriate length of segment.

Detailed simulations and validation analyses were undertaken to investigate these possible solutions. The simulations involved three geostatistical model-based methods (ordinary kriging (OK), hurdle-GAM with OK and hurdle-GAMM with OK) and a design-based method (stratified mean (SM)) were examined. Variograms at different directions (0 to 165 by 15 degree – anisotropy or no effect – isotropy) were calculated. The "best method" was selected based on giving lowest bias and the lowest root mean square error in the simulations. Comparison of geostatistical model-based methods were validated against co-located NEFSC dredge survey, VIMS dredge survey and SMAST drop camera survey abundance and biomass estimates. The "best method" was selected based on giving lowest median square error.

Based on these simulations and validation analyses researchers concluded:

- The GAM+OK method with data averaged over 750m segments was the "best" model to estimate scallop abundance and biomass and are presented in Table 1b.
- SM estimates were more accurate and precise than the model-based estimates but only when the spatial area was stratified "more correctly than might be expected in practice". However SM estimates estimated with careful stratifications provide back-up to the model-based estimates.

Weaknesses

While it appears that in the simulations the GAM+OK with data averaged over 500-1000m segments produces the "best" model further validation of these models against the other surveys demonstrates that no model performs "best" in all sub-areas. This outcome was discussed during the review meeting using an example where the model estimated the highest abundance in areas with no samples. This highlighted the requirement for rigorous oversight of model-based outcome as these can be seriously misleading if the modelled abundance and biomass estimates were used in a spatial management procedures. This results in some potential areas for further investigation including a review of the data in the sub-area to see if one or more grids contain anomaly high (or low) values and the investigation of possible edge effects resulting from the GAM smoothers requiring the addition (or removal) of nodes. Could a linear model with a quadratic form be used instead of a GAM to provide a more solid statistical basis?

Selecting a single model known to not be the "best fit" for all sub-areas and subsequently using this model across all sub-areas should be reconsidered. Selection of the most appropriate model for each sub-area should be undertaken. Presentation of the abundance and biomass estimates from all model fits should allow visual confirmation and the identification of unrealistic solutions requiring further investigation. While this adds to the work load this is preferable than using an obviously unrealistic result. Alternatively, similar to that used for stock assessment model outputs, presenting a base case and alternatives (based on differing data/model assumptions) could be another way for getting across the range and types of uncertainty.

Conclusions and overall recommendations for Term of Reference 4

Overall the approaches for estimating sea scallop abundance and biomass appear reasonable although more research is required in these area. Issues of survey design, unaccounted measurement error, model uncertainty and other identified problems will result in biases and unaccounted sources of variation in the biomass and abundance estimates. The use of these geostatistical approaches appears to be a recent initiative, however, with all the survey data continually being collected, I can envisage some very interesting analyses ahead. Another possible use of these simulations is to provide options to optimise future HABCAM surveys with the aim of using a design-based rather than model-based methods for abundance and biomass estimation.

Term of Reference 5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

All presentations addressed this Term of Reference satisfactorily. This and subsequent Terms of Reference appear to stem from the need to consolidate the current research to achieve best outcomes for the resources available. For this Term of Reference section I examine the integration of the dredge surveys, evaluate the integration of survey abundance and biomass estimates, review the cokriging analysis and briefly discuss the utility of some of the data discussed in previous Terms of Reference sections that are currently collected that may assist the management. I understood these are proposals and there are only preliminary analyses to date, so the aim here is merely to suggest where future research may be useful.

Integration of the dredge surveys

Strengths

I support the view that was presented at the review meeting that the most obvious integration is the combined analysis of survey observations collected from VIMS+NEFSC dredge surveys. Indeed there has been considerable research undertaken to facilitate, as much as possible, the data from these dredge surveys to be combined (as outlined in previous Terms of Reference sections). In recent years combining efforts between the two survey groups has attempted to ensure full coverage of the spatial area. As outlined by the researchers involved in these surveys there are still further opportunities for integration and these are discussed in the Term of Reference 7 section.

Weaknesses

Critical to integrating dredge surveys is the analysis of existing data and the development of a properly designed survey. A basic consideration would be to ensure the timing of the two surveys are such that the sea scallop populations being surveyed have similar growth and mortality processes.

Integration of survey abundance and biomass estimates

Strengths

The simplest way to integrate multiple surveys is to average the results from each survey and simple means have been used in most years to calculate averages across survey estimates. Inverse variance weighted means give more importance to surveys with lower standard errors, and have the lowest standard error of any weighted mean and therefore provide more robust estimates.

Weaknesses

Combining surveys is only appropriate if the survey biomass estimates are for the same area. Raw averaging of surveys does not account for the different precision of the estimates. However, inverse variance weighting is only reliable if there are reliable estimates of variance from each of the surveys, which is uncertain for at least the surveys with systematic designs (SMAST drop camera and VIMS dredge). As the discussed in Term of Reference 4 section the model based estimates do not take account of the model uncertainty and this would downplay this estimate in the inverse variance weighting.

There is also an assumption here that the "true" estimate lies within the bounds of these collection of surveys. This may not be the case and it is possible all surveys may under- or over- estimate the abundance and/or biomass.

Cokriging

Strengths

Cokriging was examined as a potential method of combining survey estimates for eight subregions of Georges Bank using the 2012 data from the NEFSC and VIMS dredge surveys, the SMAST drop camera survey, and the HABCAM V2 and V4 surveys. Cokriging models generally produced some minor (and occasionally major) changes to survey estimates or CVs.

Weaknesses

Results from the analysis indicated that in many subregions, sampling by one or more of the dredge surveys was insufficiently dense to build strong, stable models of cross-correlation. Furthermore two of the three surveys (Dredge and SMAST) were not designed for model-based methods and often don't have sufficient sampling density, particularly at the critical short distances, to characterize fine scale autocorrelation necessary for fitting nugget parameters.

Cokriging methods are used to take advantage of the covariance between two or more regionalized variables that are related, and are appropriate when the main attribute of interest is sparse, but related secondary information is abundant. Hence these methods yield more reliable estimates as they capitalize on the strengths of both data types. This is not the case for the cokriging between the surveys methods as seen by the results which showed very little improvements. However as the HABCAM data begins to build up a "complete" habitat map of the region and it can be demonstrated that some of the factors are related to sea scallop abundance and/or biomass, then cokriging may become a more useful model-based method for estimating abundance and biomass.

Conclusions and recommendations for Term of Reference 5

These analyses illustrated that the data combined from various surveys could be used for management purposes. By combining data from surveys it may be possible to enhance their capabilities for better management advice, particularly, since no survey method has provided complete coverage of the entire stock area on a regular basis. Perhaps the most interesting preliminary research was the presentation on cokriging as an alternative method of using all the survey data to obtain an estimate of biomass. While I didn't see any value in the current analysis, this and other similar types of analyses will become extremely useful as environmental and habitat datasets over the entire region become available. Similarly as more years of data become available another avenue for analysis is the development of spatio-temporal models. Not only would these models utilise the information on abundance and/or biomass from the previous years to fill in data gaps but would provide a predictive capacity.

Term of Reference 6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

All presentations addressed this Term of Reference satisfactorily. It appeared that one of the greatest limitations to this research was the confidence that researchers of non-scallop species place on the quality of these data. This is not surprising since the collection of unbiased data on these alternative species, etc. would introduce multiple objectives to the survey design resulting in compromises between survey objectives.

While each survey operates independently with different priorities, for ease of presentation I have summarised the information provided by the research teams under either dredge or optical surveys without reference to the particular survey team who may have provided the information. In general I considered these two survey types have similar abilities to contribute to the assessments for non-scallop species and for characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

Dredge surveys

Strengths and weaknesses

Dredge surveys have provided considerable data on specific species including aggregate counts and weights of all finfish, cephalopods and lobsters. They have also provided individual measurements as well as counts of yellowtail flounder, goosefish, Atlantic cod, and haddock, skates, winter flounder, summer flounder and Atlantic halibut. Cancer crabs and sea stars have been quantified as discussed in the Term of Reference 2 section. Iceland and calico scallops are also counted, measured and weighed in aggregate.

Furthermore for each tow, the “trash” (the remainder of the catch after the species of interest have been removed) can be quantified and the proportion of the trash that is substrate, shells, or biological organisms. Useful qualitative information on the trash is also recorded i.e. the absence, presence or dominance of dead shells of various species or groups.

Dredge survey indices are used as indices of abundance in the stock assessments of Georges Bank yellowtail flounder, goosefish, and the skate complex and could potentially be used as a recruitment index for haddock. Dredge surveys have a higher density of tows than the trawl surveys, and therefore are useful in detecting effects due to spatial management of some non-scallop species, and in particular, effects of the closures that were imposed on Georges Bank in 1994.

Dredge surveys have generally recorded detailed information on fewer species than the optical surveys which limits their contribution to ecosystem studies. However dredges are effective at capturing a suite of bottom associated species and have produced a long time series of data. The selectivity of the dredge gear differs from other commercial gears and this complementary information may assist with a greater understanding of non-scallop species.

Optical Surveys

Strengths and weaknesses

Optical surveys have the most obvious potential for attached or sessile species. Spatial and temporal patterns of density, distribution, and abundance have been investigated for species including skates, flatfishes, bryozoan/hydrozoan, epifauna, lobsters, crabs, mussels, snails and echinoderm populations including brittle stars, sand dollars, sea stars, and sea urchin spp.

Optical surveys have provided information that is not available from the dredge surveys including information from closed areas, behaviour patterns, habitat classification and broader ecosystem information.

Optical surveys are useful for collection of information on sediment characteristics and associated flora which can be used for characterization of habitats. This information can then be used to investigate habitat suitability analysis for projection of species distributions using techniques such as regression modelling and random forests. These analyses should improve our understanding of the overall ecosystem.

A key issues in these surveys is that species such as finfish are less common in images and conversely may be double counted in consecutive images (in particularly HABCAM surveys). Another issue is the reaction (avoidance) to optical gear although capturing an organism's behaviour may allow for some adjustment to the method. However the observation of diel behaviors and conditional reactions to fishing gear may also improve estimates of gear efficiency.

The ability for optical surveys in providing information on a variety of scales from fine scale studies of sea scallop ecology through to broad scale coverage which is particularly useful when contributing information to ecosystem studies including changes to community composition over time.

Conclusions and recommendations for Term of Reference 6

All dredge surveys have the potential to contribute to assessments for non-scallop species and use data apart from assessment purposes (e.g. characterizing species habitat, understanding sea scallop ecology, and ecosystem studies). In many cases the information from the various surveys is complementary. All survey methods were demonstrated to have provided information on changes in abundance of other species. Optical surveys have provided additional information on habitat and ecosystem studies not available from dredge surveys. However the dredge surveys have the advantage of long time series of data.

Term of Reference 7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

This Term of Reference was addressed satisfactorily. There was one specific proposal of options for an allocation of NEFSC/VIMS/HABCAM V4 surveys. I provided a brief comment on the proposal. In terms of the broader question of the optimal frequency and combination of survey methods, I summarised and commented on the key points made by the researchers.

NEFSC/VIMS/HABCAM V4 survey proposal

It was identified that the NEFSC scallop survey is currently funded for 36 sea days, which is not sufficient time to do the full NEFSC dredge and HABCAM surveys of both Georges Bank and the Mid-Atlantic. In the first instance considering only these two surveys, the choices for allocating time between NEFSC dredge and HABCAM operations is along the following continuum of proposals:

1. Dredge only, no HABCAM
2. Dredge survey only, with HABCAM used for special projects (e.g., paired tow work)
3. Dredge survey of both regions, with HABCAM survey in one region (potentially alternating between years)
4. HABCAM survey of both regions, with dredge survey in one region (potentially alternating between years)
5. HABCAM survey only, with dredge samples used to obtain physical samples for ageing, weights, etc., and for special projects
6. HABCAM survey only, with no dredge

Researchers considered option 4 as best, as this would allow for a continuation of the NEFSC dredge time series and allow full use of the HABCAM technology. It was noted that if the NEFSC dredge survey is allocated one third of the sea days for surveying one region, this is less than the allocation in that region for a dredge only survey, resulting in less stations and greater variance in the estimates. However this is likely to be compensated for by having HABCAM data of the same region.

By including the option of the VIMS dredge survey conducting a survey in a whole region, as occurred in 2014 in the Mid-Atlantic, option 4 would still allow for dredge surveys of both regions, thus continuing the annual time series.

Strengths and weaknesses

Dredge and optical surveys give complimentary information, therefore it is evident that any combination of surveys must include a dredge and optical approach to survey each area. As identified in the Terms of Reference sections above the integration of the NEFSC and VIMS surveys would appear to be an obvious approach for increasing overall spatial coverage of the dredge surveys although it would be important to maintain the continuity of the dredge time series of abundance and biomass estimates. It is also important to have both the commercial and research dredges towed simultaneously to provide an estimate of exploitable biomass. Given the proposed changes to the VIMS survey design it would be critical to investigate the effects of these changes on future possible integration of surveys and the impact on maintaining the continuity of the time series of abundance and biomass estimates.

Combination of surveys

Strengths and weaknesses

Better coordination between surveys would be useful. Dredge and optical surveys are considered to give complimentary information. Dredge surveys provide biological samples while non-invasive optical surveys provide for repeated, high-intensity observations in open and closed areas and potentially avoiding wasteful scenarios. Another complementary survey design is the use of large area surveys in conjunction with fine scale sampling. This survey design would overcome issues in broadscale surveys which can give unreliable abundance and biomass estimates in small areas by using dedicated high intensity surveys. This would be useful for access areas where specific sea scallop quotas need to be set. Furthermore fine scale surveys will produce fine scale maps of substrate, habitat and species association.

The sea scallop management plan is currently operating on an annual specification schedule. Given the uncertainty in the resource and how the fishery exploits it, coupled with the small spatial subunits that the management strategy operates on, there is significant value to have annual comprehensive coverage with focal areas (i.e. rotational areas that may be opening in the following year) that receive increased levels of examination. However given the cost/benefit of these surveys, there is a strong argument for maintaining their regular frequency.

A mechanism to better coordinate research proposals would be desirable. Often there are several proposals for surveying some areas, and none for other important areas. By combining resources surveys should achieve greater coverage using consistent methods and provide substantially more resources to analysis of the large amounts of data coming out of these survey methods. There will be greater certainty and hence potential improved efficiencies in extending projects to two or more years.

Conclusions and recommendations for Term of Reference 7

It was obvious that annual surveys are required to support the current management process with fishery specification adjusted every year in addition to spatial management procedures to avoid under- and over-harvesting of stock components. Preferable these surveys would occur prior and post the Scallop season, although this does not appear possible at this time. It was also highlighted on several occasions that it was important to detect and protect recruitment events. Therefore it would appear that comprehensive annual surveys are necessary. Whether it would be suitable to miss a recruitment in one year but then to pick it in the following year wasn't explored at the review meeting but would be a useful simulation exercise to determine the optimal coverage required to detect these recruitment events.

Dredge and optical surveys give complimentary information, and it is evident that any combination of surveys must include a dredge and optical approach in each area surveyed. It should be noted that given variable catchability issues of the dredge gear in some areas and that optical surveys are limited by numerous confounding factors and loss of visibility, it is not always possible to collect usable information whether the survey methods are used independently or in combination. To some extent integration has occurred where survey teams have cooperated to address survey gaps. However these surveys should be further integrated to provide standard monitoring of the entire area. All available information should be used to devise an optimal and integrated statistical survey design.

Term of Reference 8. Identify future research and areas of collaboration among investigators and institutions.

This Term of Reference was addressed satisfactorily. I summarised the key points made at the review meeting and included other areas of research identified in the previous Terms of Reference sections. I make no attempt to prioritise these.

Dredge surveys

Dredge surveys play an important role by providing a low-cost, resource assessment tool that can ground truth optical methods and vice versa. Further understanding the correlation between dredge and HABCAM observations may be a simple and intuitive approach to combine and improve estimation of sea scallop abundance and biomass.

The shellfish strata set was not specifically designed for scallops. Some of the survey strata show considerable intra-stratum spatial variability in scallop productivity. It may be desirable to design new strata specifically for scallop surveys. This task is aided by the substantial amount of existing survey data.

Given the increases in sea scallop abundance it should also be possible to reduce tow length to 7-10 mins to increase number of stations and hence overall spatial coverage. The availability of HABCAM data from tracts that cover the same areas as dredges could be used in simulations to determine appropriate/optimal tow length and I would encourage this analysis as a priority.

Bottom sediment is crudely split into two groups: sand and hard bottom. For example, dredge efficiency may be different on sand waves compared to smooth sand, or gravel/sand compared to cobble and boulders. Additional paired tows might benefit from acoustic data, such as the HABCAM V4 sidescan sonar or ship-based multibeam to more precisely characterize the bottom substrate.

Questions have been raised as to whether clogging of the survey dredge with e.g., small scallops or sand dollars, or filling of the dredge bag, affects dredge efficiency. Paired tows, both between the survey dredge and HABCAM, and between the survey and commercial dredge, could help resolve this question.

There is some potential for dredges to have a dome-shaped selection pattern which would lead to negative bias in the proportion of very large scallops in dredge length frequency distributions. This should be investigated.

There is a proposal to change the current VIMS survey design to a stratified random design using modified shellfish strata and an adaptive allocation approach for selecting stations. It would be important to consider the impact of this change in design on future integration with the NEFSC dredge survey data.

The recent reductions in sample sizes and coverage for the NEFSC dredge survey introduces some uncertainty in the quality of the survey abundance and biomass estimates (possibly less precision and potential bias). Should reductions be ongoing or further reductions occur it would be essential to investigate the impact of these on the quality of survey abundance and biomass estimates.

The estimation of sea scallop incidental mortality as a result of interaction with dredges but not captured by the dredge is important in determining the total mortality due to dredging. A before-after-control-impact experimental design to enumerate scallops in the tow path but not captured by the dredge was proposed.

Optical Surveys

Further research utilising all the data collected to date for the development of optimal statistical sampling designs for optical survey methods should be undertaken. Then use simulations to determine if it is possible to develop design-based methods for estimating abundance and biomass from optical surveys.

Investigation of appropriate statistical sampling design for subsampling (where for example too great a spacing may miss small patches and widely spaced individuals) should occur.

Greater understanding of fine scale ecology of sea scallops provides important information about potential future growth, reproduction and natural mortality, which can greatly affect the efficacy of management plans and potential yield (also using dredge survey information).

Spatial and temporal patterns of density, distribution, and abundance have been investigated for a variety of species viewed in optical surveys. Optical surveys are useful for collection of information on sediment characteristics and associated flora which can be used for characterization of habitats. This information can then be used to investigate habitat suitability analysis for projection of species distributions.

Research on other uses of the region not only increases the funding for advancing optical technology, but provides information of the impacts of these other users on sea scallops, habitats and the broader ecosystem. An example of a current project is the offshore windfarm leasing in collaboration with SMAST.

Further research is needed into automation including 2D for scallops, finfish and substrate identification and 3D using surface topography from stereo imagery for better measurements and identifying scallop pre-recruits.

Benthic rugosity and habitat classification and development of comprehensive maps are needed to determine species distributions (e.g. fine-scale habitat to provide refuge for lobsters through the first few years of their life).

Research into finfish and other non-scallop species gear avoidance behavior and gear efficiency (e.g. the diel patterns in burying and flight behavior observed for yellowtail flounder) may explain observed patterns in gear efficiency.

Inappropriate adjustments for camera edge-effects will lead to errors in estimates of the abundance and biomass of sea scallops. Alternative methods for determining whether a scallop near the edge of an image should be included should be undertaken.

Investigation into modelling approaches such as these geostatistical methods should be continued in an attempt to overcome some of the model uncertainties presented at the review meeting.

There should be development of a strategy for data storage to cater for the vast amount of data collected each year.

Conclusions and overall recommendations for Term of Reference 8

There should be development of an overall sampling strategy to ensure that all survey methods are consistent with each other.

Overall conclusions and recommendations

Surveys invariably have strengths and weaknesses which affect the quality (accuracy and precision) of estimates derived. This quality may be further eroded when surveys pursue multiple objectives which invariably result in compromises to the survey design in attempting to achieve more than one objective. Options for improving the quality of estimates include supplementary and complementary surveys. A supplementary survey is an additional survey to correct deficiencies or errors in another, while a complemented survey combines two or more survey methods that are independent and mutually exclusive, each being the complement of the other, that together provide a balanced overall survey.

The spatial nature of the management arrangements for sea scallop with open/closed areas and adaptive rotational areas further underlines the need for a solid statistical sampling design. The sea scallop surveys reviewed here independently pursue key objective along with one or more secondary objectives. Each survey method has its own strengths and weaknesses and none are specifically designed to be supplementary and complementary to each other. While there has been a considerable amount of research, there are still a number of weaknesses identified that should be investigated.

Researchers should consider the impact of any change in survey design on future possible integration of surveys and the impact on maintaining the continuity of the time series of abundance and biomass estimates. Moreover as these survey methods improve and change over time these require ongoing investigation and rectification as an essential area of research. As video technology continues to improve there will be an ongoing need to re-evaluate the measurement error of observations. However this is not all bad as improvements in optical survey may provide further insights into the dredge surveys. The ability to use dredge and optical surveys to cross validate is invaluable. Therefore it is essential that each survey system has appropriate statistical design and data collection procedures.

Obviously the key recommendation is to use all currently available information collected to date to review and update as necessary each survey method. Furthermore there should be development of both supplementary and complementary surveys to improve the coverage and quality of the estimates derived from these surveys. It is recommended that the robustness of each survey method and/or combined surveys methods be tested for sensitivity to the survey design and assumptions. Foremost is the development of an overall survey strategy to ensure that all survey methods are statistically consistent with each other. Whether there is justification for more than one of each dredge and optical method given the resources available was not apparent.

The use of both dredge and optical surveys should be considered a necessity. To some extent the VIMS dredge survey and NEFSC dredge survey are integrated because they cooperate to address survey gaps. However these surveys should be further integrated to provide a standard monitoring survey of the entire area. In terms of dredge surveys it is valuable to have both the commercial and research dredges towed simultaneously to provide an estimate of exploitable biomass and ensure the continuity of the time-series of dredge data. The optical surveys are similar approaches using the same basic concept. The SMAST drop camera survey collects multiple (4 x 4 camera types - large, small, side and still) consecutive video images. The HABCAM survey increases the number of consecutive images to 6/sec. It is inevitable that these two optical methods will converge at some point in the future as has happened with the convergence of dredge surveys over the last decade.

Combining the best features of these two optical methods to produce an overall improved optical survey method should be considered.

There should be an acknowledgement of the complexity and magnitude of work involved in processing large amount of image data collected. There were many proposals presented during the review meeting for greater automation and while these should provide more accurate and precise measurements, I would urge the need to avoid complacency and ensure ongoing calibrations and that regular ground truthing of these automation methods are built in as an essential research component of these surveys.

Overall the current approaches for estimating sea scallop abundance and biomass appear reasonable. Issues of survey design, unaccounted measurement error, model uncertainty and other identified problems will result in biases and unaccounted sources of variation in the biomass and abundance estimates. By combining data from surveys it may be possible to enhance their capabilities overall, particularly, since no survey method has provided complete coverage of the entire stock area on a regular basis. The only caution here is to consider the primary objective of each survey and that compromises are usually necessary if multiple objectives are to be addressed.

Integrating data from these different surveys more fully may not be realistic, but overcoming this limitation could lead to more accurate and precise estimates of sea scallop abundance and biomass. If it can be demonstrated that these or future survey designs are “best practice” and therefore provide accurate and precise abundance and biomass estimates, then the increased confidence of stakeholders in the overall management arrangements should guarantee acceptance of ongoing management actions taken to ensure the sea scallop stock remains sustainable. In addition, these surveys can contribute to assessments for non-scallop species and broader research questions, e.g. understanding sea scallop ecology, characterizing species habitat, and ecosystem studies.

Greater assurance of ongoing resourcing and better collaboration between institutions can only improve research outcomes. Combining the broad range of expertise within institutions and utilising the available numbers of graduate students should provide for an environment conducive to analysing the vast amounts of data that are being collected and answering the ever increasing number of questions being asked.

Critique of the NMFS review process

The Panel was well supported and ably chaired. I was impressed by the willingness and ability of the survey teams to respond to panel questions and was particularly grateful for the constructive comments provided by other review meeting participants. Several of the presentations on day 1 used all their allotted time with little left for questions and discussions. However, on the following days, more time was allowed for questions and discussions.

The survey teams provided considerable amounts of information in a logical structured approach prior and during the review. Where additional information was requested, this was readily provided by the survey teams. All background information, presentations and rapporteur notes made during the meeting were readily available via the NEFSC website. The provision of rapporteurs permitted greater focus on the discussions with the survey teams.

An important aspect of the review was that this appeared to be the first attempt to bring everyone involved in sea scallop research together, however as a consequence the review was not able to investigate and discuss the finer technical aspects of all of the numerous survey information that are available. A presentation from the perspective of management provided a critical understanding of how the survey data is being used in a management context, although details of what and how data is used in the stock assessments was not presented during the review. However future reviews could be undertaken to cover these and other individual topics in greater detail.

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TOR 4: Methods for Using Survey Data to Estimate Abundance Indices. 20p.

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Appendix 2: Statement of Work

Review of Sea Scallop Survey Methodologies and Their Integration for Stock Assessment and Fishery Management

BACKGROUND

The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Representative (COR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are independently selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

SCOPE

Project Description: On April 20, 2012, the New England Fishery Management Council voted to task its Science and Statistical Committee (SSC) "to 1) review the sea scallop HabCam survey technology and methods to determine if the HabCam is appropriate at this time for performing annual sea scallop surveys; 2) review how HabCam results will be integrated into sea scallop assessments for determining biomass and fishing mortality, and determine the impacts of reduced survey coverage from current dredge and SMAST video surveys." Further discussions broadened the scope of this task to examine all of the primary survey methods for assessing sea scallop abundance. Methods include scallop dredge surveys conducted on research vessels, scallop dredge surveys conducted on commercial vessels, the drop camera survey implemented by SMAST, and the HabCam system developed by WHOI and NEFSC. The objectives of this broadened scope are to assess the strong and weak points of each sampling approach, and identify the complementary facets of each survey methodology and opportunities for each method as part of the scallop survey sampling program going forward.

The purpose of this meeting will be to provide an external peer review of survey methodologies currently being used which provide data for sea scallop stock assessments and related fishery management models.

OBJECTIVES

The review panel will be composed of four appointed reviewers from the Center of Independent Experts (CIE), and an independent chair from the SSC of the New England or Mid-Atlantic Fishery Management Council. The panel will write the Panel Summary Report and each CIE reviewer will write an individual independent review report.

Duties of reviewers are explained below in the "**Requirements for the Reviewers**", in the "**Charge to the Review Panel**" and in the "**Statement of Tasks**". The Terms of Reference (ToRs) are attached in **Annex 2**. The draft agenda of the panel review meeting is attached in **Annex 3**.

Requirements for the reviewers: Four reviewers shall conduct an impartial and independent peer review of **sea scallop** survey methodology, and this review should be in accordance with this SoW and ToRs herein. Collectively, the reviewers shall have advanced knowledge, recent experience and:

1. Expertise in use of optical imaging in estimating abundance in marine biological surveys
2. Expertise in statistical design and estimation of surveys for stock assessments including stratified random, systematic and transect surveys.
3. Expertise with model-based estimation of abundance using geostatistical tools.
4. Expertise in the use of dredge surveys for sessile benthic organisms.

Knowledge of sessile invertebrates and spatial management would be desirable.

PERIOD OF PERFORMANCE

The contractor shall complete the tasks and deliverables as specified in the schedule of milestones within this statement of work. Each reviewer's duties shall not exceed a maximum of 10 days to complete all work tasks of the peer review described herein.

Not covered by the CIE, the Chair's duties should not exceed a maximum of 10 days (i.e., several days prior to the meeting for document review; the peer review meeting; several days following the meeting for Panel Summary Report preparation).

PLACE OF PERFORMANCE AND TRAVEL

Each reviewer shall conduct an independent peer review during the panel review meeting scheduled in New Bedford, Massachusetts during March 17-19, 2015.

STATEMENT OF TASKS

Charge to the Review Panel:
The panel will review field and analytical procedures used by each survey in estimating sea scallop abundance and biomass and collecting biological data that contribute to resource assessment and management of sea scallops and other species. Describe the strengths,

weaknesses and the opportunities for improvement in the surveys, including their methods and estimators, as an overall program that serves as a basis for abundance and biomass estimates used in annual area-based scallop fishery management procedures and triennial benchmark stock assessments. Finally, describe opportunities for using each survey in monitoring and managing resources other than sea scallops.

Each reviewer shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Tasks prior to the meeting: The contractor shall independently select qualified reviewers, without conflicts of interest, to conduct an independent scientific peer review of reports and presentations prepared by NEFSC and other groups in accordance with the tasks and ToRs within the SoW. Upon completion of the independent reviewer selection by the contractor's technical team, the contractor shall provide the reviewer information (full name, title, affiliation, country, address, email, FAX number, and CV suitable for public distribution) to the COR, who will forward this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The contractor shall be responsible for providing the SoW and ToRs to each reviewer. The NMFS Project Contact will be responsible for providing the reviewers with the background documents, reports for review, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact will also be responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COR prior to the commencement of the peer review.

<u>Foreign National Security Clearance</u>: The reviewers shall participate during a panel review meeting possibly at a government facility, and the NMFS Project Contact is therefore responsible for obtaining the Foreign National Security Clearance approval (if the meeting is held on federal property) for the reviewers who are non-US citizens. For this reason, the reviewers shall provide by FAX (or by email if necessary) the requested information (e.g., 1.name [first, middle, and last], 2.contact information, 3.gender, 4.country of birth, 5.country of citizenship, 6.country of permanent residence, 7.whether there is dual citizenship, 8.country of current residence, 9.birth date [mo, day, year], 10.passport number, 11.country of passport) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/.

<u>Pre-review Background Documents and Working Papers</u>: Approximately two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the Chair and CIE reviewers the necessary background information and reports (i.e., working papers) for the peer review. Should documents need to be mailed, the NMFS Project Contact will consult with the COR on where to send documents. The reviewers are responsible only for the pre-review documents that are delivered to the contractor in accordance to the SoW scheduled deadlines specified herein. The reviewers shall read all documents deemed as necessary in preparation for the peer review.

Tasks during the panel review meeting: Each reviewer shall conduct the independent peer review of documents and presentations in accordance with the SoW ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs shall not be made during the peer review, and any SoW or ToRs modifications prior to the peer**

review shall be approved by the COR and contractor. Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact is responsible for ensuring that the Chair understands the contractual role of the CIE reviewers as specified herein. The CIE Lead Coordinator can contact the Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

(Chair)
Act as chairperson, where duties include control of the meeting, coordination of presentations and discussions, ensuring all Terms of Reference are reviewed, controlling document flow, and facilitating discussion.

During the question and answer periods, provide appropriate feedback to the scientists on the sufficiency of their analyses and presentations. It is permissible to request additional information if it is needed to clarify or correct an existing analysis and if the information can be produced in the time allotted.

(CIE reviewers)
Participate as peer reviewer in panel discussions on validity, results, recommendations, and conclusions. From a reviewer's point of view, determine whether each Term of Reference was completed successfully. During the question and answer periods, provide appropriate feedback to the scientists on the sufficiency of their survey methods and related analyses. It is permissible to request additional information if it is needed to clarify or correct an existing analysis and if the information can be produced in the time allotted.

Tasks after the panel review meeting:

<u>CIE reviewers</u>:
Each CIE reviewer shall prepare an Independent CIE Report (see **Annex 1**). This report should comment, for each TOR as appropriate, on the strengths and weaknesses of the surveys, both individually and as a group going forward. The report should follow the guidance provided in the "Charge to the Review Panel" statement.

During the meeting, additional questions that were not in the Terms of Reference but that are directly related to the assessments may be raised. Comments on these questions should be included in a separate section at the end of the Independent CIE Report produced by each reviewer.

The Independent CIE Report can also be used to provide greater detail than the Panel Summary Report.

<u>Chair</u>:
The Chair shall prepare a document summarizing the background of the work to be conducted as part of the review process and summarizing whether the process was adequate to complete review of the Terms of Reference. If appropriate, the chair will include suggestions on how to improve the process. This document will constitute the introduction to the Panel Summary Report (see **Annex 4**).

Chair and CIE reviewers:

The Chair, with the assistance from the CIE reviewers, will prepare the Panel Summary Report. Each CIE reviewer and the chair will discuss whether they hold similar views on each ToR and whether their opinions can be summarized into a single conclusion for all or only for some of the ToRs. For ToRs where a similar view can be reached, the Panel Summary Report will contain a summary of such opinions. In cases where multiple and/or differing views exist on a given ToR, the Panel Summary Report will note that there is no agreement and will specify - in a summary manner – what the different opinions are and the reason(s) for the difference in opinions.

The chair's objective during this Panel Summary Report development process will be to identify or facilitate the finding of an agreement rather than forcing the panel to reach an agreement. The chair will take the lead in editing and completing this report. The chair may express the chair's opinion on each Term of Reference, either as part of the group opinion, or as a separate minority opinion.

The Panel Summary Report (please see **Annex 4** for information on contents) should address each of the ToRs, keeping in mind criteria in the "Charge to the Review Panel".

The contents of the draft Panel Summary Report will be approved by the CIE reviewers by the end of the Panel Summary Report development process. The chair will complete all final editorial and formatting changes prior to approval of the contents of the draft Summary Report by the CIE reviewers. The Chair will then submit the approved Summary Report to the NEFSC contact.

DELIVERY

Each reviewer shall complete an independent peer review report in accordance with the SoW including required format and content as described in **Annex 1**. Each reviewer shall complete the independent peer review addressing each ToR listed in **Annex 2**.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting in New Bedford, MA, *scheduled* during March 17-19, 2015.
3) Conduct an independent peer review in accordance with this SoW and the ToRs (listed in **Annex 2**).
4) No later than April 3, 2015, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Dr. Manoj Shivlani, CIE Lead Coordinator, via email to shivlanim@bellsouth.net, and to

Dr. David Sampson, CIE Regional Coordinator, via email to david.sampson@oregonstate.edu. Each CIE report shall be written using the format and content requirements specified in **Annex 1**, and address each assessment ToR in **Annex 2**.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

February 6, 2015	Contractor sends reviewer contact information to the COR, who then sends this to the NMFS Project Contact
March 2, 2015	NMFS Project Contact will attempt to provide reviewers the pre-review documents
March 17-19, 2015	Each reviewer participates and conducts an independent peer review during the panel review meeting in New Bedford, MA. Chair and CIE reviewers work at drafting reports during meeting
April 3, 2015	Reviewers submit draft independent peer review reports to the contractor's technical team for independent review
April 3, 2015	Draft of Panel Summary Report*, reviewed by all CIE reviewers, due to the Chair
April 10, 2015	Chair sends Final Panel Summary Report, approved by CIE reviewers, to NEFSC contact
April 17, 2015	Contractor submits individual peer review reports to the COR who reviews for compliance with the contract requirements
April 22, 2015	The COR distributes the final individual reports to the NMFS Project Contact and regional Center Director

* The Summary Report will not be submitted, reviewed, or approved by the CIE.

The NEFSC Project Contact will assist the chair prior to, during, and after the meeting in ensuring that documents are distributed in a timely fashion.

NEFSC staff and the Chair will make the final Panel Summary Report available to the public.

Modifications to the Statement of Work: Requests to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the COR within 10 working days after receipt of all required information of the decision on substitutions. The COR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: The deliverables shall be the final peer review report from each reviewer that satisfies the requirements and terms of reference of this SoW. The contract shall be successfully completed upon the acceptance of the contract deliverables by the COR based on three performance standards:

(1) each report shall be completed with the format and content in accordance with **Annex 1**,
(2) each report shall address each ToR listed in **Annex 2**,
(3) each report shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Upon the acceptance of each independent peer review report by the COR, the reports will be distributed to the NMFS Project Contact and pertinent NMFS science director, at which time the reports will be made publicly available through the government's website.

The contractor shall send the final reports in PDF format to the COR, designated to be William Michaels, via email William.Michaels@noaa.gov

Support Personnel:

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Manoj Shivlani, CIE Lead Coordinator
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Key Personnel:

Dr. James Weinberg, NEFSC SAW Chairman, NMFS Project Contact
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Dr. William Karp, NEFSC Science Director
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Annex 1: Format and Contents of Independent Individual Peer Review Report

1. The independent peer review report shall be prefaced with an Executive Summary providing a concise summary of the strengths and weaknesses of the reviewed sea scallop surveys, both individually and when used in combination.

2. The main body of the report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Key findings on work reviewed, and an explanation of their conclusions and recommendations (strengths, weaknesses of the analyses, etc.) for each ToR.

   a. Reviewers should describe in their own words the review activities completed during the panel review meeting, including a concise summary of strengths and weaknesses of the analyses and recommendations for the future.

   b. Reviewers should discuss their independent views on each ToR even if these were consistent with those of other panelists, and especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the Panel Summary Report that they feel might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The individual independent report shall be a stand-alone document for others to understand the proceedings and findings of the meeting, regardless of whether or not others read the Panel Summary Report. The independent report shall be an independent peer review of each ToR, and shall not simply repeat the contents of the Panel Summary Report.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel Membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference

(These ToRs are to be carried out by the scientists involved with scallop survey methods and analyses. The Peer Review Panel will then address the strengths and weaknesses of the various survey approaches and survey methodologies, with a focus on these ToRs.)

1. **Review** the statistical design and data collection procedures for each survey system
   a. Dredge surveys conducted on research vessels
   b. Dredge surveys conducted on commercial vessels
   c. SMAST video drop camera system
   d. HabCam camera and sensor sled

2. For each survey, evaluate measurement error of observations including shell height measurement, detection of scallops, determination of live vs. dead scallops, selectivity of gear, and influence of confounding factors (*e.g.,* light, turbidity, sea state, tide etc.)

3. Review the biological sampling aspects of the surveys, including sub-sampling procedures and the ability to sample all size classes. For each survey, evaluate the utility of data to detect incoming recruitment, assess the potential ability to assess fine scale ecology (*e.g.,* Allee effect, predator-prey interactions, disturbance from fishing gear, etc.).

4. Review methods for using survey data to estimate abundance indices. Evaluate accuracy (measures of bias) of indices as estimates of absolute abundance.

5. Evaluate any proposed methods for integrating and using surveys outside of a stock assessment model for management purposes.

6. Comment on potential contribution of each survey to assessments for non-scallop species and use of data apart from assessment purposes such as characterizing species habitat, understanding sea scallop ecology, and ecosystem studies.

7. Comment on the current and/or any proposals for optimal frequency and combination of survey methods.

8. Identify future research and areas of collaboration among investigators and institutions.

Appendix to Annex 2:

In their presentations and reports for the peer review, analysts (as opposed to the peer reviewers) will cover a broad range of topics, such as:

1. Summaries of historical scallop survey indices, and their components (e.g., frequency, spatial extent, data collected), from the NEFSC sea scallop survey, the SMAST video survey, relevant VIMS cooperative industry surveys, and HabCam surveys from WHOI and Arnie's Fisheries. For each of these surveys, additional topics include survey design, objectives, methods, and any relevant changes over time.
2. Summaries of current approaches for using abundance indices in stock assessment and management models. (Stock assessment models describe the dynamics of populations over

time and estimate total stock size and mortality rates. Management models are used to evaluate the short-term effects of alternative harvesting scenarios at varying degrees of spatial resolution.)

3. Summaries of procedures for data acquisition, post processing, archiving, availability to outside investigators, publication of derived products in primary literature, and use for stock assessments.

Rules of Engagement among analysts on Working Groups preparing for peer reviews:

Anyone participating in working group meetings that will be running or presenting results from an design or model based estimator is expected to supply the source code, a compiled executable, an input file with the proposed configuration, and a detailed description in advance of the meeting. These measures allow transparency and a fair evaluation of differences that emerge among design and model based estimates of abundance.

Annex 3: Draft Agenda

Sea scallops Survey methods review

March 17-19, 2015

(Location: New Bedford, Mass.)

DRAFT AGENDA* (version: October 17, 2014)

TOPIC		PRESENTER(S)	RAPPORTEUR

Tuesday, March 17

9 – 9:30 AM Welcome Introduction Agenda Conduct of Meeting		**Chair**	**TBD**
9:30 – 10:30 AM	Presentation #1	**TBD**	**TBD**
12:30 – 1:30 PM	Lunch		
1:30 – 3:30 PM	Presentation #2	**TBD**	**TBD**
3:30 – 3:45 PM	Break		
3:45 – 5:45 PM	Presentation #3	Chair	**TBD**
5:45 – 6 PM	Public Comments		

TOPIC		PRESENTER(S)	RAPPORTEUR
Wednesday, March 18			
9 – 10:45 AM	Presentation #4	**TBD**	**TBD**
10:45 – 11 AM	Break		
11 – 12:30 PM	Presentation #5	**TBD**	**TBD**
12:30 – 1:45 PM	Lunch		
1:45 – 3:15 PM	Presentation #6	TBD	**TBD**
3:15 – 3:30 PM	Public Comments		
3:30 -3:45 PM	Break		
3:45 – 6 PM	Presentation #7	**TBD**	TBD
7 PM	**(**Social Gathering **)**		
Thursday, March 19			
8:30 – 10:15	Review of Key Findings	Chair	**TBD**
10:15 – 10:30	Break		
10:30 – 12:30	Review/edit Panel Summary Report	Chair	**TBD**
12:30 – 1:45 PM	Lunch		
1:45 – 2:15 PM	Review/edit Panel Summary Report **(cont.)**	Chair	**TBD**
2:15 – 2:30 PM	Break		
2:30 – 5 PM	Review/edit Panel Summary Report	Chair	**TBD**

*All times are approximate, and may be changed at the discretion of the Chair. The meeting is open to the public.

The NMFS Project contact will provide the final agenda about four weeks before meeting. Reviewers must attend the entire meeting.

Annex 4: Contents of Review Panel Summary Report

1. The main body of the report shall consist of an introduction prepared by the Chair that will include the background, a review of activities and comments on the appropriateness of the process in reaching the goals of the Review. Following the introduction, for each ToR the report should address the issues described earlier in the "Charge to the Review Panel" within the "Statement of Tasks".

2. To make its determinations, the Chair and CIE reviewers should consider whether the survey methods provide a scientifically credible basis for estimating sea scallop abundance. Scientific criteria to consider include: whether the methodologies and estimators are adequate and used properly, and are leading to conclusions that are correct/reasonable. If the CIE reviewers and chair do not reach an agreement on a Term of Reference, the report should explain why. It is permissible to express majority as well as minority opinions.

3. The report shall also include the bibliography of all materials provided during the review, and relevant papers cited in the Summary Report, along with a copy of the CIE Statement of Work.

4. The report shall also include as a separate appendix the Terms of Reference (Annex 2), including any changes to the ToRs or specific topics/issues directly requiring Panel advice.

Appendix 3: Panel Membership and other pertinent information from the panel review meeting.

The review panel was composed of four scientists appointed by the Center for Independent Experts: Noel Cadigan, Martin Cryer, Jon Helge Vølstad, Brent Wise.

The review panel was chaired by J.-J. Maguire as a member of the New England Fisheries Management Council Scientific and Statistical Committee.

The review panel was assisted by the NEFSC Stock Assessment Workshop (SAW) Chairman, James Weinberg, Paul Rago, Acting Chief of the NEFSC Resource Evaluation and Assessment Division and Deirdre Boelke from the New England Fisheries Management Council.

Presentations were made by Paul Rago, Dvora Hart, Dave Rudders, Kevin Stokesbury, Scott Gallager, Richard Taylor, Burton Shank, Jui-Han Chang and Deirdre Boelke.

Toni Chute and Larry Jacobson from the NEFSC acted as rapporteurs.

A total of 49 people participated in the sea scallop survey methods review meeting.